

The Effects of Cold and Rate of Ascent on Aero-Embolism

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THE AVIATORS' disability known variously as "the bends," "aero-embolism" or "decompression sickness," is recognized as one of the most serious obstacles to high altitude flying. The basic cause is generally believed to be the release of gases from blood or other body tissues at low atmospheric pressures, but there is still much doubt and controversy as to the exact manner in which nitrogen, carbon dioxide and other gases are released from the body fluids, how they produce the joint pains and other forms of distress, and the reasons for the wide variation in time of onset and severity of the symptoms. The best general discussion of the physiology of high altitude decompression sickness is to be found in Armstrong's "Aviation Medicine"¹, while papers by Behnke², Fulton⁴ and Rainsford⁹ provide summaries of more recent work.

Since a thorough understanding of the physiology of high altitude decompression sickness may well lead to improved methods of prevention or therapy, many experimental studies of the bends have been made in low-pressure chambers. However, almost all of these

studies have been made at normal room temperatures, so that the extreme cold usually encountered simultaneously with the bends at high altitudes has not been reproduced, nor have its effects on the incidence of the bends been studied in detail.

The main purpose of our experiments was to study the relationship between body temperature and the incidence of bends. Our low-pressure chamber is situated inside a refrigerated cold room, and we made repeated exposures of the same subjects to low pressures (equivalent to 35,000 feet) under varying conditions of temperature and clothing. Experiments were conducted in the cold with the subjects wearing heavy or light clothing or electrically heated flying suits. Control exposures to low pressures were also carried out at normal room temperatures (80-85° F.) with the subjects wearing summer clothing. The results showed a definite increase in the incidence of bends when the subjects were cold, in comparison with experiments when electrically heated suits were worn or when the chamber was at 80 to 85° F.

Another variable which has been widely believed to affect the incidence of bends is the speed of "ascent" or rate of reduction of air pressure. Pure oxygen is ordinarily breathed through-

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out most of the ascent, and breathing any such nitrogen-free gas mixture before ascent is known to reduce the incidence of bends, presumably by allowing time for the nitrogen in the body fluids to be partially eliminated. Hence it is logical to conclude that at least part of the protection from bends achieved by a slow ascent is due to the longer period during the ascent in which nitrogen-free oxygen is breathed. On the other hand, the rate of decompression itself might be expected to affect the formation of bubbles in body fluids which are supersaturated with nitrogen. We were able to study separately the two factors of denitrogenation during ascent and rate of ascent *per se*; and the results indicate that rate of ascent *per se* is more important than the time available for denitrogenation, at least during the ascent of 1,000 or more feet per minute.

METHODS

1. General

The pressure chamber used for these studies is situated within a refrigerated room and was kept within 5° F. of the temperature chosen for each experiment. Various temperatures from +32° to -5° F. were selected for the ascents in the cold, and approximately equal numbers of subjects wore each type of clothing at each temperature. The experiments in warm air were at 80 to 85° F. All subjects were supplied with oxygen from standard Army Air Force demand regulators and demand oxygen masks. Whenever the subject or observer had any doubts about the tightness of any mask's fit, a continuous flow of oxygen was supplied by opening the emergency valve. Pres-

ures are expressed as equivalent altitudes, and the terms ascent and descent refer to changes in pressure only. The measurements of equivalent altitude used in this paper are accurate within 3 to 5 per cent, the figures for rate of ascent within 5 to 10 per cent.

The eighteen subjects were men ranging in age from 19 to 40 years. The number of experiments for each subject varied between 4 and 35. They were all in good health and were experienced in low-pressure chamber work. They reported all symptoms promptly with estimates of severity on the widely used scale where:

+ = mild
 ++ = moderate
 +++ = severe, ordinarily resulting in removal of the subject from the chamber
 ++++ = collapse

All experiments were scored according to the method of Ferris, Webb, Ryder, Engel, Romano and Blankenhorn³ where five points are credited for each 15 minutes during which the subject is without symptoms. Four points are allowed for each 15-minute period during which + bends occurred, three if ++ bends occurred, and two if +++ bends occurred, except that only one point was allowed for the period during which the subject was taken from the chamber. All experiments were terminated at three hours after reaching altitude so that a perfect score was 60 points.

Skin temperatures were measured during the experiments in the cold by means of four thermocouples taped to the base of the large toe, the outer side of knee, and the outer side of elbow, and the chest.

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TABLE I. SKIN TEMPERATURES AND INCIDENCE OF BENDS

Clothing	Skin Temperatures				Difference in Average Bends Score. Scores When Warm Minus Scores for Light Clothing
	Trunk	Elbow	Toe	Knee	
	Degree F. 95-100	Degree F. 90-100	Degree F. 60-85	Degree F. 80-100	
Electrically heated					12
Heavy clothing	90-95	80-90	50-80	80-90	2
Light	85-95	75-85	50-70	70-85	—

2. Clothing

During the experiments at 80 to 85° F. the subjects wore normal summer clothing and were comfortably warm at all times. During experiments in the cold, three types of clothing were worn and they are designated as: *light*, *heavy* and *electrically heated*.

The *light* clothing varied with the exercise to be performed. When the subjects sat or lay still they wore one pair of heavy underwear (50 per cent wool) and jacket and trousers of "windproof" cotton with wool kersey lining. When they were to exercise they wore two pairs of the heavy underwear and a hard twill cover-all suit similar to those widely used by mechanics. The following additional items were always included in the light clothing:

- 2 or 3 pairs wool ski socks
- felt booties
- jute socks
- canvas mukluks with soft leather soles
- knitted wool gloves
- fur mittens
- wool scarf
- knit wool toque, shearling flying helmet or wool-lined helmet

The insulation value of the light clothing including kersey-lined jacket and trousers is approximately 2 Clo⁵. The subjects wearing this clothing were definitely cold and often shivered slightly.

The *heavy* clothing consisted of one pair of heavy underwear plus trousers and parka made from a double layer of alpaca pile with a windproof outer shell. The men wore the same hand-head- and foot-wear listed above for the *light* clothing. This heavy clothing had an insulation value of about 4 Clo, and it kept the subject in a state best described as chilly but not definitely uncomfortable.

The *electrically heated* clothing consisted of:

- 1 pair heavy underwear (50 per cent wool)
- standard F-1 U. S. Army Air Forces electrically heated suits with heated gloves and boots
- standard Air Forces shearling lined boots
- the same wool-lined trousers and jacket included in the light clothing
- knit toque, shearling helmet or wool-lined helmet

The electric heat was controlled by the subjects, who were instructed to adjust the rheostat so as to keep themselves comfortably warm but not overheated to the point of sweating.

The skin temperatures characteristic of these three types of clothing are presented in Table I.

3. Activity

Since exercise has been shown to be an important variable affecting the incidence of the bends, we used four contrasting conditions of activity in

these experiments: (1) lying as still as possible, (2) sitting on a chair or bench with exercise limited to reading and occasional slight shifting of position for comfort, (3) chair-arm push-ups, in which the subject lifted his entire weight by pushing up from chair arms, fully extending his arms and lowering his body slowly to the chair once every minute after altitude was reached (chair arms 10 inches above seat), (4) the knee-bend exercise developed by Ferris et al.³ Every three minutes after altitude was reached the men performed five deep knee bends in rapid succession. In using this exercise we followed the procedure used by Ferris et al.³, discontinuing the exercise 90 minutes after reaching altitude and sitting quietly for the remainder of the 3-hour period.

4. Rate of Ascent

(a) *1,000 feet per minute ascents.*—For most of the experiments a 1,000 feet per minute ascent was used in which the "automatic mix" valves on the oxygen regulators were set at the ON position for the first ten minutes of the ascent. At this setting they provide a mixture of air and oxygen which is automatically varied with altitude so that the partial pressure of oxygen is kept somewhat above that at sea level. During the first ten minutes, the rate of ascent was about 1,500 feet per minute so that it was possible to make a rapid drop from 10,000 to 7,000 feet to test for ear troubles and return to 10,000 feet at the end of the ten minutes. After the tenth minute the automatic mix valves were turned to the OFF position so that they delivered pure oxygen for the remainder of the ex-

periment. The ascent continued above 10,000 feet at 1,000 feet per minute so that 35,000 feet was reached at thirty-five minutes. During twenty-five of these thirty-five minutes pure oxygen was breathed.

(b) *5,000 feet per minute ascents.*—In the 5,000 feet per minute ascent the automatic mix valves were on the ON position from 0 to 10,000 feet and then changed to OFF. After first reaching 10,000 feet there was a drop to 7,000 feet to test for ear troubles. This test and the return to 10,000 feet ordinarily required one or two minutes, so that the total time required to reach 35,000 feet was eight or nine minutes.

(c) *Pre-oxygenated 5,000 feet per minute ascents ("5,000 Pre-ox").*—To test the relative effects of rate of ascent and pre-oxygenation we conducted several experiments with what we have called a "pre-oxygenated 5,000 feet per minute ascent" abbreviated in Figure 2 "5,000 pre-ox." During the first ten minutes, this procedure was exactly like that used in the 1,000 feet per minute ascents. At ten minutes the automatic mix valves were changed to the OFF position and the chamber dropped to sea level. The subjects remained at sea level, breathing pure oxygen, until twenty-eight minutes, and then the chamber was raised at a rate of 5,000 feet per minute so that it reached 35,000 feet at thirty-five minutes. Thus the time spent breathing pure oxygen was the same as during the 1,000 feet per minute ascents (twenty-five minutes) while the actual rate of ascent was at least as rapid as during the 5,000 feet per minute ascents. If the extra oxygen provided by

the 1,000 feet per minute ascent is the sole factor affording protection from bends, this control series should give the same incidence of bends as the 1,000 feet per minute ascent. If, on the other hand, rate of ascent *per se* is the chief factor favoring slow ascents, this control series should give results similar to the 5,000 feet per minute experiments.

RESULTS

1. Effects of Cold

The effects of cold on bends susceptibility can be reliably judged only by comparing the same subject's symptoms when warm and when cold. This precaution is necessary because our subjects varied widely in their susceptibility to the bends. In order to make a rapid survey of the important factors affecting the incidence of the bends we exposed our subjects to varying rates of ascent and varying exercise as well as to varying thermal environments. Consequently, it is necessary to make paired comparisons between the bends scores for the same subject with exercise and rate of ascent held constant. Such comparisons are made in Figure 1, where each point represents the difference between the average scores for a given subject when warm and when cold. The "cold" scores were obtained when wearing the light clothing described above and the three types of "warm" scores represent (1) subjects in warm air (80-85° F.), (2) subjects in the cold but with ample electrical heat, and (3) subjects in the cold wearing the heavy clothing described above, which kept them definitely cool but not shivering.

It is clear from Figure 1 that the

subjects had considerably higher scores and were thus less susceptible to the bends when they were in warm air or in electrically heated suits than when they were wearing the light clothing. On the other hand there was only a very small increase in their scores when wearing the heavy clothing.

The differences plotted in Figure 1 for warm air and electrical heat are statistically significant, since "Student's t" test shows a probability of less than 0.01 that such differences could be obtained by chance. The difference between heavy and light clothing, on the other hand, would have occurred by chance in sixty-three out of 100 samples of this size according to "student's t" test, and the difference is thus of no significance.

Not only were the average bends scores higher among the warm subjects, but the time of onset was delayed and a greater proportion remained three hours at altitude without symptoms or with only + or ++ bends. The higher bends scores with electric heat as opposed to light clothing can also be seen in Figure 2, since scores are plotted for five subjects when warm and when cold at different rates of ascent.

The skin temperatures of our subjects were analyzed in search of further correlations with bends susceptibility (Table I). There is great variability in skin temperatures depending upon the individual, the length of the exposure, and the exercise performed so that there was a wide range of skin temperatures under each condition. The analysis indicated that there was no higher correlation between the skin temperatures of the subjects and their

bends scores than the correlation shown in Figure 1 between bends scores and type of clothing. The skin temperatures of the subjects in heavy

the same for men who were chilly as for men who were definitely cold and shivered from time to time.

In seeking an explanation for these

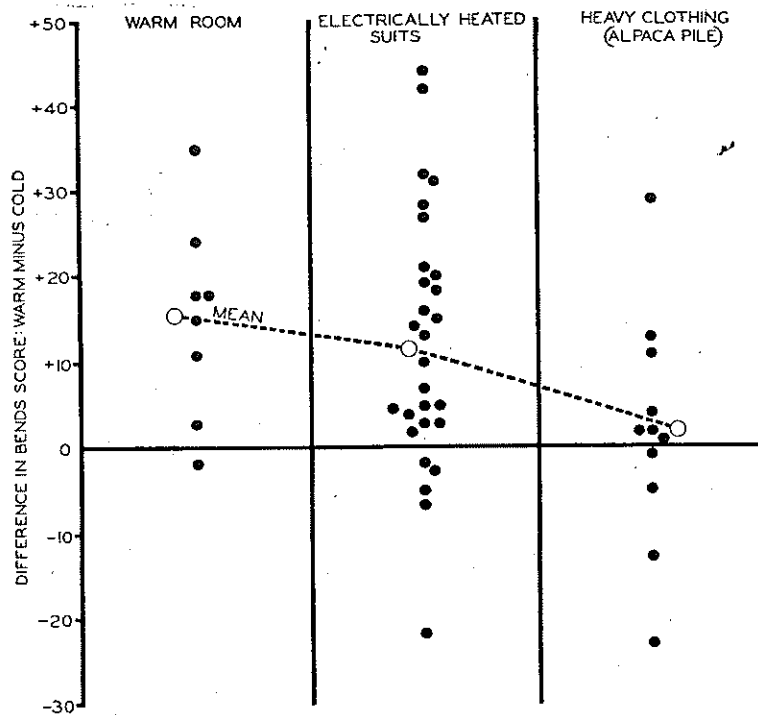


Fig. 1. Effects of temperature on the incidence of bends. The ordinate is the difference in bends score between warm and cold; three types of warm conditions are shown in the three columns; the cold conditions refer to the light clothing described in the text. Each point represents paired data (warm and cold) for the same subject with exercise and rate of ascent held constant. Thus each point above the zero line indicates that one man under one set of conditions was less susceptible to bends when warm than when cold.

clothing were intermediate between those characteristic of electrically-heated clothing and those of men wearing light clothing, while bends scores indicate no significant difference between men wearing heavy and light clothing.

Thus the beneficial effects of warmth are apparent only when the subject is comfortably warm. The incidence of bends was approximately

results, it is natural to suspect that shivering was responsible for the higher incidence of bends in the cold subjects, in view of the fact that exercise is quite effective in eliciting joint bends (see below under *activity*). However, the men wearing heavy clothing did not shiver except in rare cases, and yet this group had practically as low an average score as the subjects in light clothing who shivered quite often.

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Perhaps the important factor is the muscle tenseness associated with even slight chilliness, such as occurred in both the lightly dressed subjects and In both the heavy and light clothing, the men were cool enough to undergo general peripheral vasoconstriction. Perhaps this is an important factor by

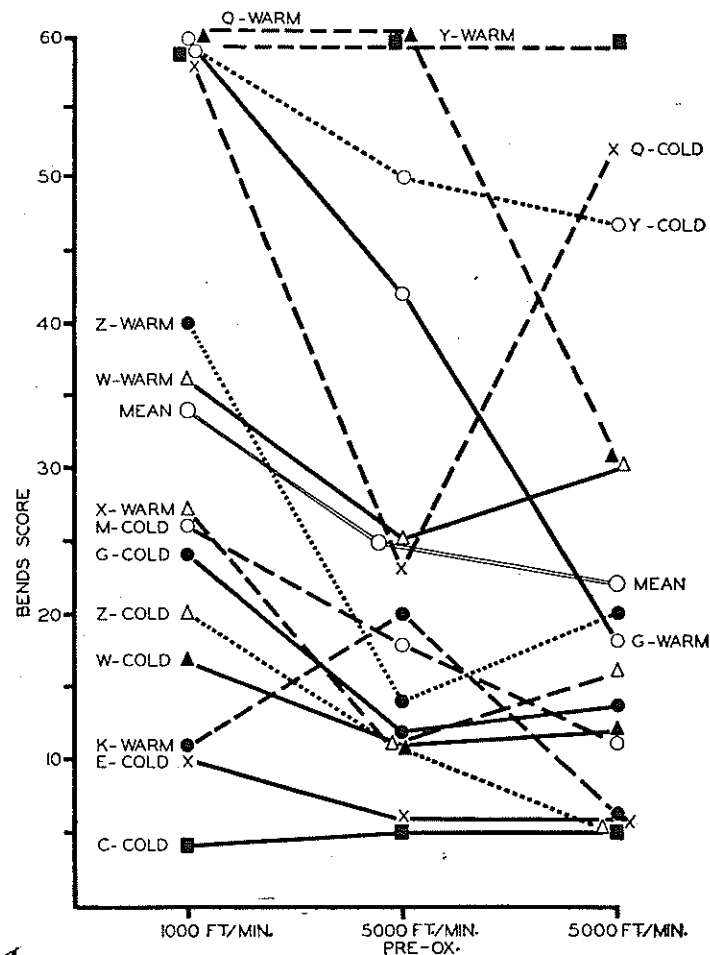


Fig. 2. Effects of rate of ascent on the incidence of bends. The individual subjects are designated by letter. The men wore either electrically heated clothing (points designated as "warm") or the light clothing described in the text (points designated as "cold").

those wearing heavy clothing. Could such a muscle tenseness be analogous to the straining movements shown by Ferris, et al.³, to be so effective in eliciting the bends?

which cold increases the incidence of bends. Such vasoconstriction, to be effective, must presumably affect the tissues surrounding the joints where the pain actually occurs.

It is interesting in this connection that Whitaker, et al.¹⁰, found that bullfrogs were more likely than rats to have bubbles in their veins when decompressed after exercise. Their interpretation was that CO₂ accumulated during the exercise, but that it was washed away by the rapid circulation of the rat, while the bullfrog's circulation was so slow that considerable CO₂ remained to form bubbles at reduced pressure. Both the cold-blooded bullfrog and the vasoconstricted limb of a man have poor circulation, while there is a rapid circulation through the tissues of a normal limb or an active, warm-blooded rat.

The experiments of Whitaker, et al., involved very rapid decompression to pressures equivalent to 40,000 to 50,000 feet, and one must be cautious in interpreting this analogy between our results with human subjects and those of Whitaker, et al., with frogs and rats. We feel, however, that vasoconstriction may be an important factor influencing the incidence of bends, and that it merits further study.

Regardless of any theoretical explanations, however, the data show clearly that it is very advantageous from the point of view of protection from bends to keep aircrews comfortably warm during high altitude flights.

2. Rate of Ascent and Pre-oxygenation

Figure 2 gives the data on ten subjects who were exposed to the three rates of ascent described above, in order to test the effect of rate of ascent *per se* on the incidence of bends. All of these experiments were performed at +20° to +30° F. Each curve repre-

sents a given man in the same clothing; "warm" signifies electrically heated clothing and "cold" means light clothing. All subjects performed the standard exercise of Ferris, et al.³—a series of five full knee bends in close succession at three-minute intervals.

The ascents designated "5,000 pre-ox" were made at 5,000 feet per minute but were preceded by a short period of pre-oxygenation so that the time on pure oxygen was the same as during the 1,000 feet per minute ascents. The scores for "5,000 pre-ox" ascents were generally closer to the 5,000 feet per minute scores than to those resulting from 1,000 feet per minute ascents. The difference between the 1,000 and 5,000 pre-ox ascents is statistically very significant* (probability of occurrence by chance less than 0.01), whereas the difference between 5,000 pre-ox and 5,000 is of no significance and could have occurred by chance in 40 samples out of 100 according to "Student's t" test.

Thus the difference in bends susceptibility between fast and slow ascents seems to be largely due to rate of

*Since five of the 1,000 feet per minute scores plotted in Figure 2 were 60, the experiment did not test these subjects' susceptibility fully, because a score of 60 means three hours without symptoms after which the subject was removed from the chamber without testing the possibility that bends might have appeared at some later time. On the other hand there were only three scores of 60 at the fast ascents, so that a more extensive scoring scale would presumably not have raised the average appreciably. In other words, the difference between scores from 1,000 feet per minute and pre-oxygenated 5,000 feet per minute ascents would probably be greater if the full range of susceptibility had been tested. It is also interesting to note that the very susceptible subjects (C, E and V) as well as the bends resistant subject, Y, showed little alteration of score with changing rates of ascent.

TABLE II. TYPES OF DECOMPRESSION SICKNESS OCCURRING IN THIS STUDY

(Includes only completed experiments where the subject was removed because of +++ bends or remained three hours at 35,000 feet. Uncompleted experiments omitted from this tabulation were those in which the experiment was terminated due to the necessity for a rapid removal of another subject from the chamber.)

Total cases remaining three hours at 35,000 feet without symptoms.....	29
Cases of joint bends.....	131
Cases of "chokes".....	16
Cases of nausea.....	7
Total	183

*These can be described as respiratory distress typified by coughing and sensations of asphyxia.

ascent *per se* while the amount of pre-oxygenation during the slow ascents is relatively unimportant.

3. Activity

We found that the bends score of a subject is lowered as the severity of the exercise he undertakes at altitude is increased. The bends were generally, but not always, located at the joints exercised. The four states of activity we used averaged as follows in order of increasing bends scores: chair-arm pushups, knee bends, sitting, lying. This confirms the work of Ferris, et al.³, who found that human subjects were more likely to suffer from bends if they exercised at altitude. The experiments of Harris, et al.⁶, Harvey, et al.⁷, McElroy, et al.⁸, and Whitaker, et al.¹⁰, show that muscular exercise facilitates the formation of bubbles in decompressed bullfrogs, rats, rabbits, goats and chickens.

4. Incidental Observations

Table II contains a tabulation of the types of decompression sickness occurring in this study.

All of the eighteen subjects had joint bends one or more times and nine had at least one case of chokes, questionable chokes or nausea. The number of experiments for each man varied from four to thirty-five. Unmistakable cases of the chokes occurred in three men, and questionable cases in four others. Four men were forced to descend because of nausea, and one had cases of both nausea and questionable chokes on different days.

The cases of nausea showed a consistent pattern of symptoms. First a feeling of slight nausea and discomfort led the subject to turn on extra oxygen believing that he might be anoxic. The oxygen would produce no improvement, the feeling of nausea would increase, often rapidly, and the subject frequently felt weak or faint. There was sometimes considerable malaise and persistence of nausea for several hours after descent, but no cases of actual vomiting occurred. These symptoms were quite distinct from the nausea and faintness characteristic of anoxia, being unaffected by a forced flow of pure oxygen and persisting after return to normal conditions.

Scintillating scotomata occurred in about six cases, usually but not always after cases of chokes or nausea. Two subjects reported migraine headaches persisting from one to several hours after cases of chokes or nausea. The first migraine headaches ever experienced by one of us (RD) occurred after his last two cases of rather severe chokes. Scintillating scotomata accompanied these headaches.

Only one case of swelling and edema following bends occurred; the morn-

TABLE III. ANATOMICAL LOCATION OF BENDS

(Many cases reported bends at several sites)

Site (as reported by subject)	+ or ++ bends	+++ or ++++ bends
Foot	9	0
Ankle	23	11
Knee	31	62
Hip	7	4
"Lower leg"	8	8
"Upper leg"	8	2
Hand	17	3
Wrist	36	4
Elbow	30	8
Shoulder	23	14
"Lower arm"	15	2
"Upper arm"	22	4
Collar bone	2	0
Chest and Sternum (not chokes)	4	1
Skin	6	0

ing after subject W had experienced severe wrist bends, the affected hand and wrist were swollen and somewhat sensitive to touch. These symptoms persisted for two days. The same subject frequently had skin tingling, usually when wearing an electrically heated suit, and on one other occasion he reported aches and stiffness (also in joints where bends had occurred) persisting for a day or two after the experiment. Two other subjects experienced residual stiffness on the day following an experiment.

Table III contains a list of the sites at which bends occurred. It is interesting to note that most of the severe and incapacitating joint pains were located in the knee, shoulder or ankle while the mild or moderate symptoms were more widely distributed.

CONCLUSIONS

1. During simulated ascents in a refrigerated altitude chamber, men kept comfortably warm suffered significantly less from joint bends than they did when they were definitely cold. The average time of onset was later in the warm group; twice as many were able to remain for three hours at 35,000 feet without symptoms, and the average bends score (method of Ferris, et al.³) was increased by an average of 12 points, a difference which has a probability of statistical significance greater than 99:1.

2. This partial protection from joint bends was achieved either when the experiments were conducted in warm air (about 80° F.) or when the subjects wore adequate electrically heated clothing.

3. However, heavy alpaca clothing, without electrical heat, did not reduce the incidence of bends significantly from the rate found in the same subjects when definitely cold. In this heavy alpaca clothing the subjects were reasonably comfortable but chilly and probably vasoconstricted.

4. In other words, warming the subject seems to be effective in reducing the incidence of bends only if the skin temperatures are kept at levels as high as those characteristic of warm environments. It seems probable that peripheral vasodilatation is the essential factor.

5. The use of adequate electrically heated clothing or adequate cabin heating should thus be helpful in reducing the incidence of bends at high altitudes.

6. Comparison of the incidence of bends at rates of ascent of 1,000 and

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5,000 feet per minute showed a markedly greater susceptibility after the faster ascents. The longer period of pre-oxygenation achieved during a 1,000 feet per minute ascent was not the chief factor responsible for the lower incidence of bends, for a control series with equal pre-oxygenation but a rapid ascent gave almost the same scores as uncomplicated 5,000 feet per minute ascents.

7. Some symptoms and after effects of chokes and nausea are described.

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REFERENCES

1. ARMSTRONG, H. G.: Principles and Practice of Aviation Medicine. Baltimore: Williams and Wilkins Co., 1939.
2. BEHNKE, A. R., JR.: Investigations concerned with problems of high altitude flying and deep diving; with application of certain findings pertaining to physical fitness to the general military service. Chapter in War Medicine, a symposium. Ed. by W. S. Pugh, pp. 406-409. New York: Philosophical Library, 1942.
3. FERRIS, E. B., WEBB, J. P., RYDER, H. W., ENGEL, G. L., ROMANO, J., and

BLANKENHORN, M. A.: Personal communication.

4. FULTON, J. F.: Physiology of high altitude flying, with particular reference to air embolism and the effects of acceleration. Chapter in War Medicine, a symposium. Ed. by W. S. Pugh, pp. 357-367. New York: Philosophical Library, 1942.
5. GAGGE, A. P., BURTON, A. C., and BAZETT, H. C.: A practical system of units for the description of the heat exchange of man with his environment. *Science*, 94:428-430, 1941.
6. HARRIS, M., BERG, W. E., WHITAKER, D. M., TWITTY, V. C., and BLINKS, L. R.: Carbon dioxide as a facilitating agent in the initiation and growth of bubbles in animals decompressed to simulated altitudes. *J. Gen. Physiol.*, 28:225-240, 1945.
7. HARVEY, E. N., McELROY, W. D., WHITELEY, A. H., WARREN, G. H., and PEASE, D. C.: Bubble formation in animals, III. An analysis of gas tension and hydrostatic pressure in cats. *J. Cell. & Comp. Physiol.*, 24:117-132, 1944.
8. McELROY, W. D., WHITELEY, A. H., COOPER, K. W., PEASE, D. C., WARREN, G. H., and HARVEY, E. N.: Bubble formation in animals, VI. Physiological factors: the role of circulation and respiration. *J. Cell. & Comp. Physiol.*, 24:273-290, 1944.
9. RAINSFORD, S. G.: The more recent additions to our knowledge of the effects of compression and decompression on man and the application of this knowledge to the practical problems connected with high flying and deep diving. *J. Roy. Nav. M. Serv.*, 28:326-332, 1942.
10. WHITAKER, D. M., BLINKS, L. R., BERG, W. E., TWITTY, V. C., and HARRIS, M.: Muscular activity and bubble formation in animals decompressed to simulated altitudes. *J. Gen. Physiol.*, 28:213-223, 1945.

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